PERFORAMANCE OF HAYABUSA-2 LIDAR IN ACCEPTANCE AND VERIFICATION TESTS. N. Namiki[1], T. Mizuno[2], H. Senshu[3], R. Yamada[1], H. Noda[1], M. Shizugami[1], N. Hirata[4], H. Ikeda[5], S. Abe[6], K. Matsumoto[1], S. Oshigami[1], F. Yoshida[1], N. Hirata[7], H. Miyamoto[7], S. Sasaki[8], H. Araki[1], S. Tazawa[1], Y. Ishihara[2], M. Kobayashi[3], K. Wada[3], H. Demura[4], J. Kimura[9], M. Mita[2], K Kawahara[2], H. Kunimori[10], M. Hayakawa[2], and N. Kobayashi[2], [1]NAOJ (Mizusawa, Oshu, Iwate, JAPAN 023-0861; nori.namiki@nao.ac.jp), [2]ISAS/JAXA (Sagamihara, Kanagawa, JAPAN 252-5210), [3]PERC/Chitech (2-17-1 Tsudanuma, Narashino, Chiba, JAPAN 275-0016), [4]Univ. Aizu (Aizu-Wakamatsu, Fukushima, JAPAN 965-8580), [5]ARD/JAXA (Tsukuba, Ibaraki, JAPAN 305-8505), [6]Nihon University (Funabashi, Chiba, JAPAN 274-8501), [7]Univ. Tokyo (Tokyo, JAPAN 113-0032), [8]Osaka University (Toyonaka, Osaka, JAPAN 565-0043), [9]Tokyo Institute of Technology (Tokyo, JAPAN 152-8550), [10]NICT (Koganei, Tokyo, JAPAN 184-8795).

Introduction: The first Japanese asteroid mission, Hayabusa, visited the small asteroid 25143 Itokawa in September 2005. Images taken by Hayabusa were combined with other remote sensing observations to reveal that this small asteroid (500 m at its longest axis) is the first rubble-pile body identified in our solar system [1]. Despite several failures of the spacecraft that occurred during and after rendezvous, Hayabusa successfully returned samples from the surface of 25143 Itokawa to Earth in 2010 to reveal new aspects of a small asteroid [1-5].

JAXA and collaborating scientists developed the second asteroid mission named "Hayabusa-2". Hayabusa-2 is based on the heritage of the first Hayabusa. At the same time, Hayabusa-2 is implementing improved engineering systems and scientific investigations with new and challenging objectives. Furthermore, the target asteroid is different from that of the first Hayabusa mission. The asteroid 25143 Itokawa explored by Hayabusa is silicate-rich S-type. On the other hand, Hayabusa-2 will be investigating a C-type asteroid, (162173) 1999 JU_3.

Hayabusa-2 was launched from Tanegashima Space Center on December 3 2014. After Earth swing-by in December 2015, Hayabusa-2 will arrive at the asteroid in June 2018. During the rendezvous phase of about one and half year, the asteroid will be observed carefully to reveal the shape and the surface properties by Multiband Imager, Near Infrared Spectrometer, Thermal Infrared Imager, and Laser Altimeter (LIDAR).

LIDAR measures the altitude of the spacecraft from the surface of the asteroid by measuring the time of flight of the reflected laser pulse. As a part of Attitude and Orbit Control System (AOCS), the LIDAR data are used for navigation of the spacecraft and are particularly important during touchdown operations. In addition, the LIDAR data are essential for the scientific analysis of the shape, mass, and surface properties of the asteroid in order to elucidate the physical evolution of minor bodies such as impact fragmentation and coagulation. Hayabusa-2 also will expand on the Itokawa exploration by investigating the uniformity and variation of porosity within the rubble-pile body and detecting dusts levitating above the surface of the asteroid. The remote sensing observations of Hayabusa-2 will be carried out from the Home Position (HP), middle altitude, and low altitude whose distances from the asteroid surface are nominally 20 km, 5 km, and 1 km, respectively.

Design of Hayabusa-2 LIDAR is based on that of the first Hayabusa [6, 7]. The size and weight are 241 x 228 x 289 mm (Figure 1) and 3.52 kg, respectively. Performance of LIDAR was confirmed in acceptance and verification tests during integration of the instrument and the spacecraft. Laser pulses of 15 mJ at 1064 nm wavelength are emitted from a passive Q switched Nd:YAG laser at 1 Hz rate. The 1.5-mrad FOV corresponds to surface footprint diameter of 30 m at HP. A Cassegrain type telescope of 110 mm in effective diameter is used as a primary receiver to measure distance greater than 1 km. In addition, another receiver optic is implemented for range measurement shorter than 1 km and longer than 30 m. These telescopes are named “Far” and “Near”, respectively. Light reflected from the surface is refocused onto a silicon avalanche photodiode (Si-APD) through a narrow band-pass interference filter. Telemetry and command are transferred between LIDAR and the ground station via the AOCS. The range data passed to AOCS are used to keep the spacecraft a safe distance from the asteroid or

Table 1. Specification of Hayabusa-2 LIDAR.

Parameter	Value
Altitude range	30 m ~ 25 km or longer
Range resolution	0.5 m
Range accuracy	± 1 m (at 50-m altitude)
(1σ)	± 2.0 m (at 25-km altitude)
Pulse repetition rate	1 Hz
Receiver telescope	Cassegrain type
Effective diameter	110 mm (Far)
of telescope	3 mm (Near)
Pulse energy	15 mJ
Pulse width	7 nsec
Pulse divergence	2.5 mrad
Field of view	1.5 mrad (Far)
	20.4 mrad (Near)
Receiver detector	Si-APD
Power consumption	18 W (including LD heater)

for a controlled touchdown approach. The LIDAR has a large radiator (Figure 1) because of the severe thermal environment that all instruments will experience onboard Hayabusa-2 at the time of touchdown.

Hayabusa-2 LIDAR will provide a resolution of a round-trip time less than 3 ns corresponding to 0.5-m one-way range resolution. Overall, Hayabusa-2 LIDAR is sufficient for spacecraft navigation, but does not have as high a performance as the OLA instrument planned for OSIRIS-Rex [8, 9]. To compensate for the performance of the instrument, we need to take advantage of the experience gained from operating the first Hayabusa mission.

Fig. 1. An appearance of Hayabusa-2 LIDAR.

Ranging Performance: During the rendezvous phase, topographic data will be acquired constantly from HP to cover the entire surface of the asteroid. Then the topographic data will be used to measure shape of 1999 JU_3. The shape model is not only crucial for safe touchdown and sampling, but also is necessary to estimate a porosity of the asteroid. The required accuracy for the shape model is less than 5.5 m. Thus the performance measured in the verification tests (Table 1) satisfies this requirement.

The mass of 1999 JU_3 is also necessary for the porosity estimate and is measured while the spacecraft is freely approaching to and departing from the asteroid. The requirement of accuracy for the mass measurement is 10 m at the middle and low altitudes. In comparison, test results proved that the range accuracy is 0.6 m at middle altitude and is better at low altitude.

Albedo Measurement: During the range measurement, LIDAR also provides the integrated intensity of the transmitted and returned pulses allowing an assessment of the surface albedo including shadowed areas. Designed accuracy of albedo measurement is 46 % with respect to the average value of 0.06. This value is significantly larger than the scientific target of 20 % or less. We have been challenging to improve such performance, but have not reached to the goal yet. The accuracy is 25 % or worse depending on a ratio of transmitted and returned energy. This ratio varies with temperature. We plan further calibration tests using a proto flight model of LIDAR which is expected to show the same performance with the flight model regarding the albedo measurement.

Dust Count Mode: Hayabusa-2 LIDAR is equipped with a new function called "dust count mode". This new function is aimed to detect a very weak scattering light from a dust cloud around the asteroid, if ever exists [10-12]. For this purpose, we requested three kinds of modification to LIDAR. First, a range of 1 km needs to be divided into 50 bins in the dust count mode, thus a spatial resolution of the dust detection is 20 m along the line of sight. Second, wait time that is a parameter to start 1-km range needs to be variable from 0 to 19 km so that we can observe dusts at any altitude lower than and equal to HP. And third, the threshold level is variable in four levels, at least, allowing to distinguish the abundance of dust particle in step-wise manner. These requirements are all satisfied. In particularly, the threshold are set to be 64 levels. Their performance has been confirmed by a verification test.

Optical Transponder System: Hayabusa-2 LIDAR is also equipped with a function for laser link experiment. "Optical transponder" system enables LIDAR to receive the laser pulse from a ground SLR station and to send back a return pulse to the same ground station. The laser link experiment will be carried out at a time of Earth swing-by which is scheduled in December 2015. We have tested the optical transponder system, and verified that the optical transponder system can adequately process double pulses from the ground station.

Further Calibration: In order to improve the accuracy of albedo measurement, and to check performance of the dust count mode, we need additional tests using the proto flight model. Because the proto flight model is not exactly the same as the flight model, the calibration data shall be carefully applied the observation data that will be obtained in the rendezvous phase.

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